A New Magnetic Device for the Identification of Endotracheal Tube Position

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Abstract- **A new device for detecting the position of endotracheal tube is presented in this paper. This device consists of a high sensitive linear Hall-effect sensor and a newly designed endotracheal tube in which two small magnets are embedded. The Hall-effect sensor can be placed on the skin of neck over the vocal cord to detect the position of endotracheal tube by measuring the strength of its magnetic field when the magnet on tube passes through the glottis during intubation. The results of our clinical tests on 38 cases of endotracheal intubation and 15 controls of esophageal intubation show that the device is sensitive to verify the esophageal intubation, and that it provides a useful means for clinician to control the inserted length easily. Due to its unique principle of operation, the detector can be applied to all kinds of patients, especially in pre-hospital sites.**

Keywords- **Endotracheal tube, endotracheal intubation, esophageal intubation, Hall-effect sensor, magnetic detection**

I. INTRODUCTION

Endotracheal intubation is a necessary therapeutic means for many patients in operation theatre, intensive care units (ICU) and emergency departments. In order to establish an open airway or to maintain respiration by mechanical ventilation, an endotracheal tube (ETT) is intubated into the trachea of those patients. However, an improper placement of ETT can cause serious incidence in those departments, especially in pre-hospital situations. The ETT may be inserted into the esophagus or pass carina into one of the bronchi by mistake (Fig.1). It may move above the glottis after placement due to the movement of patient or ventilator tube. All these complications may lead to irreversible brain damage and death [1].

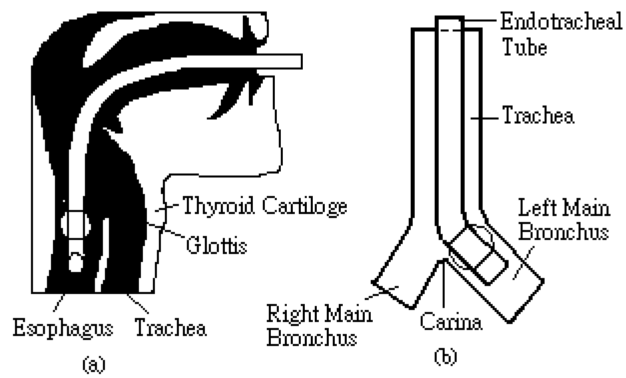

Fig.1 Improper endotracheal intubations (a) going into the esophagus, and (b) passing over the carina.

There are several methods and devices to detect endotracheal intubation [2], such as capnographyic detection, FETCO2 detector [3], acoustic reflectometry [4], self-inflating bulb and syringe detector [2]. However, there are various limitations with these devices. Capnography is complex to operate and is impossible in pre-hospital situations. The accuracy and sensitivity of FETCO2 can be influenced by ambient temperature, humidity. Additionally, the FETCO2 detector is not reliable during cardiopulmonary resuscitation and for patients with carbonated beverage in the stomach [3]. The effectiveness of self-inflating bulb and syringe detector remains suspicious in morbidly obese, pregnant patients and infants [5,6].

Hall-effect sensor is sensitive to magnetic flux density and plays a great role in the detection of object's position. This paper proposes a new detector on the basis of magnetic detection.

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Abstract

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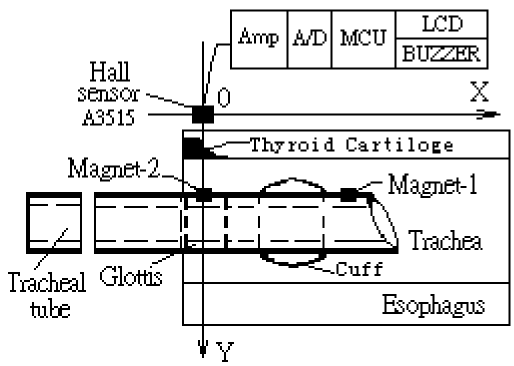

Fig.2 A schematic diagram of the detection system.

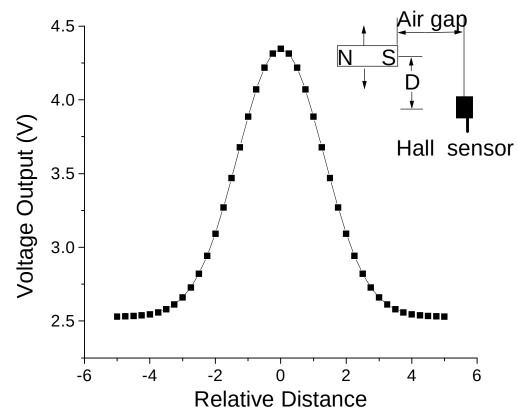

Fig.3 The experimental gauss curve for the fixed air gap, where D is the distance between the magnet and the sensor.

II. METHODOLGY

A. Magnetic Detector

The proposed detection system (Fig.2) uses an A3515 (Allegro Microsytems Inc.) [7], which is a temperature-stable linear Hall-effect sensor sensitive to small changes of magnetic flux density. It provides a voltage output that is proportional to the applied magnetic field and has a quiescent output voltage that is approximately 50% of the supply voltage. The Hall-effect sensor A3515 has an output sensitivity of 5 mV/G (Gauss), and a linearity of nearly 100% (±800Gauss). It can be combined with magnet in different ways. In this system, the unipolar slid-by method is utilized, in which the magnet passes the sensing surface at a fixed distance (Fig.3). The output voltage of sensor is a curve that can be approximated with a Gauss equation [8]

$$V(s) = c + a\ell^{-(d-d_0)^2 b} \quad ,$$

where c is the voltage offset, a is the amplification factor, b is the form factor, and d_0 is the displacement offset. An experimental gauss curve is shown in Fig.3.

The output voltage of the sensor is input to an instrument amplifier AD620 (Amp, Fig.2, Analog Devices Inc.) with a gain factor of 200 and is then sampled by a 12 bits analog to digital converter (A/D) at the frequency of 10 Hz. A microcontroller (MCU) controls the A/D and calculates the distance between the Hall sensor and the magnet. The result of calculation is displayed in the liquid crystal display (LCD). Meanwhile, an audible alarm from a buzzer will be heard when the position of ETT is recognized.

B. Endotracheal Tube

Two small magnets, magnet-1 and magnet-2, are embedded in the wall of a common ETT (Fig.2). They generate magnetic field, which could be detected by the Hall-effect sensor. The number and location of magnets in the tube are based on the purpose to achieve an effective detection. For example, magnet-1, between the cuff and the tip of the tube, can be used to confirm the esophageal intubation. The magnet-2, about 1.5cm to the rear cuff edge, can be used to control the intubated length. It is a recommended length of intubation if the vocal cord is over the magnet-2 after intubation.

C. Principle of Operation

Assuming that the origin of a coordinate is on the neck skin surface over the thyroid cartilage immediately above the glottis (Fig.2). The task is to carry out a two dimensions position detection of the ETT. Prior to intubation, the Hall sensor is fixed on the origin.

In the X direction, when the magnet-1 gets near to the glottis during intubation, the magnetic field strength (Vmfs, Fig.4) detected by the sensor increases greatly. If the variation of the magnetic field (denoted by Vchange) exceeds a threshold value (Vth, Fig.5), an alarm will be released, indicating that magnet-1 has passes through the glottis. If the intubation continues, a second alarm will be

heard when magnet-2 passes though the glottis. Thus, the inserted length of the tube could be determined.

In the Y direction, the tracheal lumen width in adults is about 1.0-2.0cm. If the endotracheal tube is inserted into the esophagus by mistake, the field strength detected is too weak to cause an alarm when the magnet got through the glottis. Thus the esophageal intubation can be verified by this approach.

D. Clinical Evaluation

In this study, 38 patients were evaluated in elective surgery requiring tracheal intubation between 1 Jan. and 1 Mar. 2001. Endotracheal intubation was performed in all cases, of which 15 controls were taken esophageal intubation with the identical ETT (in forms of diameter, type and length).

To test the function of alarm, 15 magnetic strength values were recorded continually by the detector in every subject. One value was measured at the moment of alarm, seven before and seven after that moment.

III. Results

In endotracheal intubations the alarm sounded in all 38(100%) cases. In esophageal intubation, the alarm depended on the threshold value (Vth). When the value of

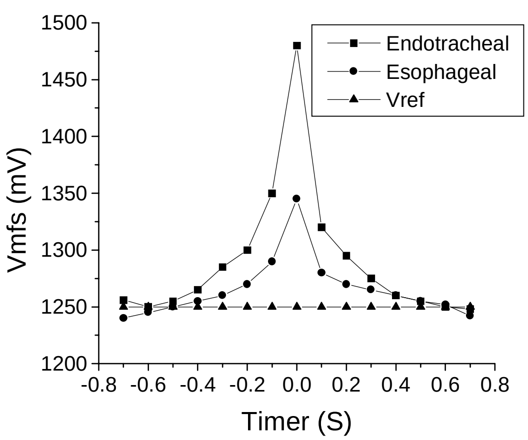

Fig.4 The strength of magnetic field from one patient during intubation. The peak of the curve is the moment of alarm when the magnet is passing through the glottis. Vref is the field strength of air in the absence of magnets.

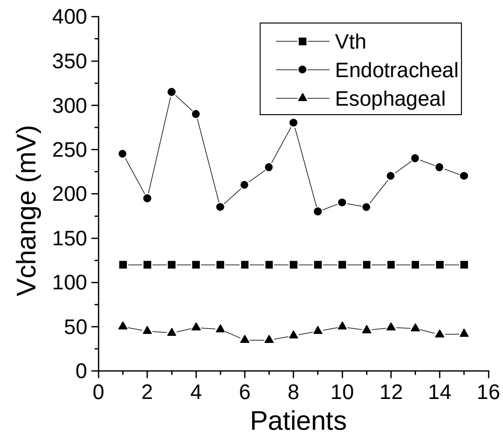

Fig.5 The highest value of Vchange=Vmfs-Vref (at the moment of alarm) detected in 15 different patients. Vth (120 mV) is a threshold value for decision-making.

Vth was low (40mV), alarm displayed in all 15 (100%) cases. When the value of Vth increased to 120 mV, no alarm could be heard.

The typical magnetic field strength value obtained during intubation is shown in Fig.4. Before or after the moment of alarm, the field strength decreased rapidly, indicating that the field strength in trachea was very distinguishable between the moment of alarm and other times. In contrast, it was not so apparent in esophageal intubation.

In 15 controls (Fig.5), the minimum variation of magnetic field strength (185 mV) in endotracheal intubation is distinctively greater than the maximum of variation (58 mV) in esophageal intubation. Therefore, esophageal intubation can be verified by setting a proper threshold value (120 mV in this study).

IV. Discussion and Conclusion

The detector proposed in the paper is simple, portable and easy to operate. Besides a LCD display, the device also provides an audible alarm for the detection of tube position during endotracheal intubation, so no special training is required for operation.

Because this method does not depend on ventilation, neither on the presence of exhaled carbon dioxide, the detector has a great advantage over other detection devices. This device can be applied to all kinds of patients, including pregnancy woman, patients in cardiopulmonary arrest,

patients with morbidly obese, patients with carbonated beverage in stomach, and patients with airway injury or obstruction.

The threshold value (Vth) is determined by the depth from the skin to the trachea at the level of vocal cold and by the diameter of tracheal lumen. Patients at different ages have different dimensions of trachea lumen. However, by adjusting the threshold or being embedded a different magnet, the detector should be suitable for all age groups.

Due to the magnetic field strength is not linear to the distance between the magnet and the sensor, the output of the Hall sensor, as a function of distance, is nonlinear as shown in Fig.3. Through a ROM look-up table in MCU, the compensation for the nonlinearity of magnetic as a function of distance can be realized. In this table, one field strength value is corresponded to one point of distance. After this procedure, the result displayed on LCD will be the actual distance between the magnet in the ETT and the Hall sensor.

This device is sensitive to detect esophageal intubation and is easy in controlling the intubated length. However, further clinical evaluation based on a large database should be performed to verify its reliability, stability and accuracy.

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